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OPTIMIZATION OF PROCESS PARAMETERS FOR ELECTROCHEMICAL MICRO-MACHINING TO DRILL MICRO HOLE

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Abstract -To fully use the capabilities of Electrochemical Micro-Machining (EMM), thorough study is required to optimise the different EMM process parameters in order to increase material removal, surface quality, and accuracy. With this in mind, an indigenous creation of an EMM machine set-up has been explored in order to conduct a systematic investigation for establishing sufficient control over EMM process parameters in order to fulfil micromachining criteria. In this work, an EMM machine with mineral water was constructed, and tests were done to investigate the effects of some of the important process parameters on machining rate and accuracy, such as machining voltage, mineral water electrolyte concentrations, pulse on time, and machining current.Experiments using 304 Stainless Steel (SS) sheets were used to evaluate the influence of tool electrode tip form on EMM. The form of the tool electrode tips has a considerable impact on the machining rate and overcut.

Keywords:-EMM, Micro ECM, DC supply , Grey Relation

1. INTRODUCTION

The demand for miniaturization of differentultra precision items used for making highly precision machines and equipmentsrequire the development of manufacturing processes which are capable enough of executing micro manufacturing activitiesMicromachining is the process of removing tiny amounts of material with diameters ranging from microns to millimetres. Micromachining is the most common method of producing miniature parts and components. Miniaturization will continue in the future, with micromachining technology becoming more important, as long as consumers require optimal space utilisation with more effective and higher quality products. Micromachining is the generic term for machining with dimensions of 1–999 mm, and it is possible that this is the true definition of the term. However, it also refers to machining that cannot be accomplished using traditional methods[1]. On very small and thin work pieces, various ultra precision machining acticities are performed which is known as advanced micromachining. Mainly in electronic and computer industry fields, small and micro-holes, slots & complex surfaces has to be made in multiple numbers, every now and then in a single work piece. When such things are done using traditional machining techniques, difficulties like excessive tool wear rate and heat production at the tool and work piece interface, as well as changes in work piece material properties, etc., are common[2]. In traditional machining of small and deep holes, complicated surfaces, or forms, tool rigidity requirements constitute an additional serious difficulty. Furthermore, machining three-dimensional forms becomes more complex.There are some specific advantages which are exploitable during micromachining operations through which non-conventional machining processes are getting their importance.Electrochemical machining (ECM) was first used in aerospace and other heavy sectors in the late 1950s and early 1960s for shaping and finishing operations. All of these technologies currently play a key role in the production of a wide range of parts, from the machining of massive metallic items with complex forms to the opening of micron-sized windows in silicon. [3].

Electrochemical micromachining (EMM) is a type of electrochemical machining that is used to create ultra-precision forms in the micromachining range. Chemical micromachining is currently used to produce the majority of metallic components (CMM) [4], Most applications involving micromachining of metallic components can benefit from the use of EMM. EMM, particularly in the micro manufacturing realm, needs to better understand high rate anodic dissolution processes if it is to become a commonly used manufacturing method in the electronic and precision manufacturing sectors. Despite the fact that academics from a variety of institutions throughout the world have begun some study, this field of micromachining still need a great deal more research.To meet the micromachining requirements, an attempt has been made to make an EMM setup to achieve satisfaction and control of ECM process parameters, carried out in depth independent research, also keeping in view of the above requirements of the EMM.The method known for removing metal by an electrochemical process is known as ECM. For machining mostly hard material and for the mass production, this method is normally used. Also those materials which are hard to make or machine by using conventional methods, ECM works.It has limits for its usage to electrically conductive material. This method shows that the two electrodes i.e. a positive charged anode and the negative charged cathode is put down in a liquid such as sodium chloride(electrolyte), and when the current is forced between the two electrodes, the reduction of material from anode starts.In this process, two of the electrodes are placed very close to each other without letting them touching. In ECM on an atomic level, material removal takes place.

In electrochemical machining (ECM) An electrolyte flows through the machining gap between the work piece and the tool which are held closely together. The anode is known as the workpiece and cathode is known as the tool. The metal of the anode dissolves locally when the current is passed through them in an electrolyte so the shape of the tool is complementary to the shape of the workpiece. The electrolyte is fastly pumped through the machining gap to remove the generated heat from the dissolved material. The mechanical properties of the anode material play no part in the electrochemical method. To compare it with other machining methods like spark machining where there is no direct contact of workpiece and tool. ECM has a benefit of removing metal very fast irrespective of the machining surface and their dimensions. It also has an advantage of no wear of tool. While machining any complicated shapes can be formed and also no burrs are formed during machining. This method doesn't have limitations but the equipments used for ECM is more complicated.

Electrochemical micromachining

Electrochemical machining is an anode suspension method which was primarily made to machine difficult to cut items. It is based on the basic electrolysis which is processed under the governance of Michael Faraday's laws [1]. Electrolytes are responsible for conducting electricity in electrochemical micromachining also known as MICRO ECM. Cycle of Machining in this method is independent of metal hardness factor. This method has wide range of advantages that are highly useful but also has many disadvantages linked to it. Discussed below are some advantages as well as some disadvantages.

Advantages: Equipment wear and tear is finished; electricity consumption is low and is done on less voltage when compared to other methods with greater removal rates; burr is not formed in this process; complex profiles can be made of hard metals that are conductive with this process; working infrastructure has no heat related harm to it; it is useful for production at a large scale and also helps in reducing manpower and cost cutting on labor.

Disadvantages: when production is carried out on a large scale, lots of energy is required for functioning which is about one hundred times more than that of energy used in conventional method of drilling the steel; which functioning, hydrogen gas is evolved in this method which is an explosive gas, it needs to be handled very carefully as it can cause a threat to the facility; can be used only for conduction metals and is useless when considered for non conducting metals; Electrolyte is used in this method which needs to be handled with care and is difficult to handle a large amount of electrolyte.

Applications: electrochemical micromachining is used for various purposes now a days. Used in production of moulds and dies, complex shaped materials such as turbine blades, and also used for making various components related to aerospace work, deburring. Parts used in fuel injection system, ordnance machinery, etc.As indicated in figure 1.1, the anode, or work piece, is linked to the positive polarity, while the cathode, or shaped tool, is attached to the negative polarity. It also depicts how electricity is used to remove the material from the anode. As the electrolyte flows through the narrow inter electrode gap, the heat created during the machining process flushes the sludge away.

1.1. Fundamental Principles

While process of electro-machining, chemical reactions takes place on both electrodes that is, at the work piece which is at anode and at the tool which is at cathode, both being submerged in the electrolyte. In the reaction, electrons and free ions pass through the electrolyte (phase boundaries) which help in carrying out the operation at both anode and cathode..

For the meantime, to understand the energy distribution in electro-machining system, potential difference needs to be studied basically. Figure 1.2 Basic potential calculations other major concepts are shown in this figure. Electrode reversible potential is calculated using Nernst equation. Three main overpotentials which are known in electrochemical reactions are activation, concentration and resistance overpotentials. These can be estimated with the help of Tafel equation, ohm's law and diffusion layer.

2. LITERATURE SURVEY

In this chapter, we broadly classify all the research paper into three different categories, i.e. paper related to tool design, related to surface finish and some paper related to type of electrolyte used.

2.1. Overview based on tool design on MICRO ECM

AixiSunaet al.[1] This research looks at laser machining and electrochemical machining (LM-ECM) of metal micro-holes. The heat effect of a millisecond pulsed laser etches metallic materials, then electrochemical machining removes the recast layer. On the wall of metal micro holes, no recast layer is formed. The precision and efficiency of machining have been increased. Laser machining micro-hole modelling is established, as is metal micro-hole modelling for electrochemical machining. The models establish the main process parameters of LM-ECM. The effects of process parameters on experimental outcomes are examined, and optimum values are provided. A comparison is given between the LM-ECM and single machining techniques. The testing results demonstrated that the material surface of LM-ECM is cleaner and free of molten slag than that of single laser machining.

Craig Smith and Philip Koshy[2], In order to improve the performance of electrical discharge machining (EDM) processes, the creation and development of advanced online monitoring schemes is still a must. Currently, the information used to regulate EDM is primarily comprised of indices obtained from voltage/current waveforms that reflect the status of the process.

D. Zhu et al. [3] presents a finite element method for precisely determining electrode profiles. Because the suggested method does not require an iterative designing procedure, it achieves good convergence and computing efficiency. In MICRO ECM, tool design is primarily concerned with estimating gap distribution for a particular work-piece geometry. The accuracy of machining is determined by the accuracy of tool design. In this study, the electrolyte concentration was 150 g/l, and the anode was made of low carbon steel. An average difference of less than 4% between practical and theoretical findings was obtained in the MICRO ECM experiment.

Yuming Zhou et al. [4] propose a novel strategy for overcoming problems such as restricted applicability, inaccuracy, and non-convergence that occur while designing tool (cathode) in electrochemical machining using a finite element method with an optimization formulation. Even cathodes with corners, edges, and cusps can be built using the finite element method's versatility, provided that appropriate representations are used. Overall, the approach presented here has a lot of potential for tool design in electrochemical machining procedures.

C. S. Chang et al. [5] In electrochemical machining, the effect of thermal fluid characteristics on the numerical modelling of the tool form for a particular work-piece shape was discussed. The fluid field of the electrolyte is predicted using a bubbly two-phase, one-dimensional flow model and a one-phase, two-dimensional flow model, respectively. The vacancy percentage is the most critical component in determining the electrolyte conductivity and the shape of the work-piece, according to the findings. When correct machining conditions are chosen, the effect of thermal-fluid characteristics should be included in the inverse problem, and the relative inaccuracy of the related work-piece can be minimised to roughly 0.002.

S. J. Ebeid et al. [6] By hybridising the technique with low-frequency vibrations, researchers were able to improve machining accuracy in MICRO ECM. The work focuses on developing mathematical models for linking the inter relationships of various machining parameters such as applied voltage, feed rate, back pressure, and vibration amplitude on overcut and conicity in order to achieve high controlled accuracy. The approach used in this study is response surface methodology (RSM). To improve the performance of MICRO ECM, hybridization procedures are used. The goal of this study is to improve machining accuracy in MICRO ECM by combining the process with low-frequency vibrations. The response surface methodology utilised in this study has proven to be a useful tool for analysing the MICRO ECM process, with the amplitude of tool vibration being the most important factor affecting MICRO ECM accuracy. After the tool amplitude approaches 80 m, however, this impact fades.

3. EXPERIMENTAL SETUP AND TOOL DESIGN

3.1. Experimental Objectives

It is vital to identify and understand the elements impacting the material removal rate (MRR), overcut diameter, and overcut depth of MICRO ECM in order to analyse them. The parameters influencing the responses were investigated through a series of machining tests utilising AISI P20 tool steel as the work-piece. AISI P20 tool steel has numerous qualities, including being a pre-hardened high-tensile tool steel with quick machinability under toughened and hardened conditions without the need for further heat treatment. This avoids the risk, expense, and time involved with heat treatment, as well as the potential of deformation and even breaking

3.2. Experimental Setup

From MetatechIndustry, the whole experimemtal setup is conducted on Electrochemical Machining set up which has input Supply of - 415 v +/- 10%, 3 phase AC, 50 HZ. Output supply is 0-300A DC at any voltage from 0-25V and has better efficiency more than 80 percent at partial and full load condition. The cable insulation resistance has atleast 10 Mega ohms with 500V DC, also comprises of three major sub systems which are being shared in this chapter, the setup having all major three sub systems of them are as follows:

1. Machining setup
2. Control Panel
3. Electrolyte Circulation

4. PROBLEM FORMULATION

This experiment proposes an ecologically friendly, high-precision, and low-cost technique of ECMM utilising mineral water as the electrolyte instead of the previously utilised acid or neutral solutions, such as H_2SO_4 and $NaNO_3$, to tackle environmental difficulties and increase the application range of ECMM. A fresh new way of micro pin creation is also presented, which employs a high-voltage power source, and the inter-electorde voltage change has been tested and monitored to demonstrate how successful this approach .It also have proposed the use of mineral water to be used as an electrolyte and aniodic dissolution. As far as the impact on environment and machine setup maintanence has been involved, compare to the traditional acid or neutral solutions, mineral water is completelyfresh and clean, friendly to environment, and corrosion free.

5. EXPERIMENTAL WORK

In this chapter experimental work is discussed which is based on Taguchi orthogonal array L16. MRR,The work piece's overcut diameter and depth were measured, and Grey relational analysis was used to determine the optimal parameter settings.

5.1. Taguchi Experimental Design and Analysis

Taguchi's comprehensive system of quality engineering is one of the engineering achievements of the 20th century. His focus was mainly on the methods of the engineering strategies and their effective application rather than advanced statistical techniques. Shop-floor quality engineering and upstream both are included in his system. His upstream methods is mainly cost effective and is easy to use long lasting design for large scale production & market place, it also efficiently uses small scale experiments so as to reduce variability.Shop floor tactics are used to maintain quality in production and to monitor real-time processes. It also offers output at a low cost. When the most upstream quality approach is used, it creates higher leverage on improvement while simultaneously reducing cost and time.Taguchi'sphilosophy is createdby the followingthree very easy and fundamental concepts:

- Quality should be designed into the product and not inspected into it.
- Quality is best achieved by minimizing the deviations from the target. The product or process should be so designed that it is immune to uncontrollable environmental variables.
- The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Taguchi suggests an "off-line" strategy to improve the qualitybeing an alternate to an attempt to to check the quality in a product on the production line. He observes that inspection, screening and salvaging process is not able to improve its poor quality. The quality of the product cannot be put back by any amount of inspection. Taguchi mention a three-stage process: system design, parameter design & tolerance design. The effect of process parameter is being studied by the present work of taguchi's design approach on the various responses of the MICRO ECM process.

5.2. Experimental Design Strategy

Taguchi's suggested orthogonal array (OA) for laying out of experiments. These OAs are Graeco-Latin squares especially. Selecting the most relevant OA and assigning the parameters and interactions of interest to the proper columns is the first step in designing an experiment. Taguchi recommends using linear graphs and triangular tables to simplify parameter assignment. The array drives the experimenters to create tests that are almost identical. The Taguchi technique analyses the outcomes of the trials in order to attain one or more of the following goals:

- To establish the best or the optimum condition for a product or process
- To estimate the contribution of individual parameters and interactions
- To estimate the response under the optimum condition

The perfect state is demonstrated by evaluating the parameters and their primary consequences. The primary effects of each parameter may be seen in the broad trends of influence. The analysis of variance (ANOVA) is the most common statistical procedure for determining the percent contribution of each parameter in the outcomes of tests that are inconsistent with a defined degree of confidence.The study of the ANOVA table for the given analysis shows the parameters which needs the control. The analysis of variance (ANOVA) has been performed in the present investigation. The effect of the selected MICRO ECM process parameters on the selected responses have been investigated through the plots of the main effects based on ANOVA.

5.4 Effect of machining and pulse on time

Different tool electrode tip shapes shows the voltage on machining rate. The machining rate increases with the increase of pulse on time and machining voltage shown in figure 5.4-5. The increase in rate of machining happens because with the increase in pulse on time and machining voltage,the current density required for material dissolution increases. Towards the machining zone, the use of flat tip tool electrode reduce the machining rate because of the improper supply of the electrolyte. Apart from that, across the face of the tool, the truncated cone tip electrode produces a higher amount of machining rate as it allows the sufficient flow of the electrolyte. When compared with the top portion, the bottom portion of the diameter of tip is lesser, in conical with rounded tip. At an preliminary stage of machining, to the workpiece surface, the bottom portion of the tip is exposed first. Howeverthe exposed tip is small in diameter, the potential essential for material removal is adequateenough and therefore the machining rate is faster. When compared to conical with rounded tip and flat electrode with less accuracy, wedged electrode has a greater machining rate. In the case of the wedged electrode, the current density distribution is narrow, which increases current localization and results in a better machining rate.

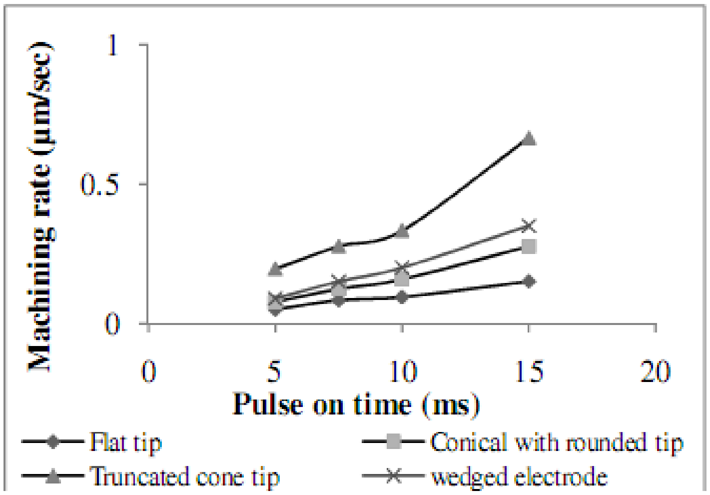

Figure 5.4 Effect of pulse on-time on machining rate (Machining voltage: 10V, Electrolyte concentration: 0.29mole/l and Frequency: 50 Hz)

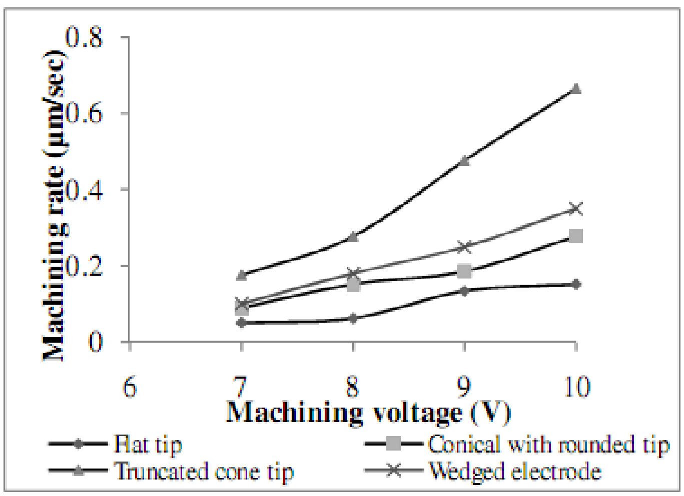

Figure 5.5 Effect of machining voltage on machining rate (Pulse on-time: 15ms, Electrolyte concentration: 0.29mole/l and Frequency: 50 Hz)

5.6. Grey relation analysis

In the grey relation analysis, experiment data, that is, responses that are measured, are normalised in the range of 0 to 1 at first. This is known as the process ofgrey relation generation. According to this data, grey relation coefficients are calculated to show the correlation between the perfect (best) and the real normalized experimental data. Generally, grey relation grade is then determined by averaging the grey relation coefficient corresponding to selected responses. The calculated grey relation grade is known for the overall quality characteristics of the multi responses process and depends on it.

5.7. Conclusion

Experiments are showedconferring Taguchi method which uses machining set up and the considered Rotary U-shaped tubular electrodes. The control parameters like voltage&feed,concentration of electrolyte and electrode's diameter were varied to conduct 16 different experiments. A Mould cavity can be produced by this process. The MICRO ECMmethod parameter set voltage at 15v, feed 0.6 mm/min, electrolyte concentration 50 g/l and tool diameter 4 mm has maximumgrey relational grade. Therefore, this input parameter is setto the ideal machining parameters for highest MRR and lesser for overcuts of both of them concurrently with in the experimental domain.

6. RESULT AND DISCUSSION

In this chapter the effect of process parameter on responses such as MRR, Overcut diameter & Overcut depth are analysed.

6.1. Analysis of Experiment and Discussions:

6.1.1. Effect on MRR

The machinability of MICRO ECMare determined by the electrolyte and their electrical conductivity, electrode feed rate, inter electrode gap and electrolyte flow rate. The impactcaused by different machining parameters on MRR (means) are shown in Fig. 5.1. The MRR is enourmously gets effected by the electrode feed rate and as feed rate gets increased it also increases. As the machining time decreases, the material removal rate increases with feed rate to give the expected result.With voltage and electrolyte concentration, MRR also increases; but the effect caused is lesser than the feed rate on MRR, while by increasing the tool diameter MRR decreases and the effect of tool diameter and electrolyte concentration has lesser effect on RR and doesn't give any conclusive evidence of any impact on RR.

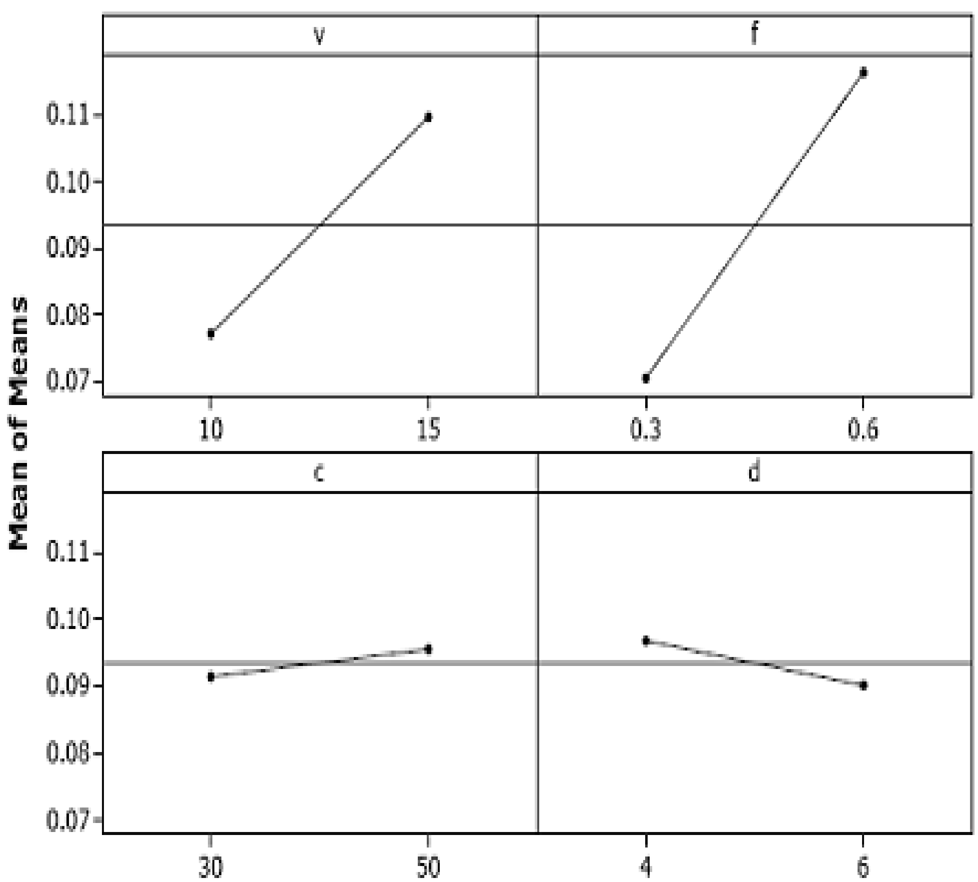

Figure 6.1: Main effect Plot for MRR

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